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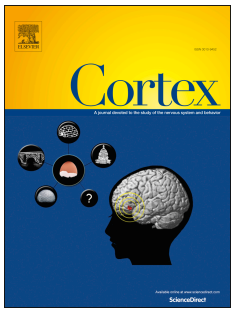

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The influence of REM sleep and SWS on emotional memory consolidation in participants reporting depressive symptoms

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Abstract

Negative emotional memory bias is thought to play a causal role in the onset and maintenance of major depressive disorder. Rapid Eye Movement (REM) sleep has been shown to selectively consolidate negative emotional memories in healthy participants, and is greater in quantity and density in depressed patients. Slow-Wave Sleep (SWS) is typically associated with the consolidation of non-emotional memories. However, the effects of REM sleep and SWS on emotional memory consolidation have not been investigated in participants reporting depressive symptoms. In this study, we recruited two groups of healthy participants; one reporting mild-to-moderate depressive symptoms, and another reporting minimal depressive symptoms (assessed using the Beck Depression Inventory; BDI-II). Using a within-subjects split-night design, we measured consolidation of positive, neutral and negative images across a 3 h retention interval rich in either REM sleep or SWS. We found a significant sleep condition x image valence interaction in participants reporting depressive symptoms [$F(2, 20) = 4.73$, $p = .021$], but not participants reporting minimal depressive symptoms [$F(2, 22) = 0.17$, $p = .845$]. Participants reporting depressive symptoms consolidated significantly more neutral memories during SWS, and marginally more negative memories during REM sleep, than those reporting minimal depressive symptoms [$t(21) = 2.44$, $p = .023$; $t(21) = 1.96$, $p = .064$, respectively]. Our preliminary results demonstrate that REM sleep and SWS have differential effects on the consolidation of emotional and neutral images in participants reporting depressive symptoms. Further studies including larger sample sizes are required to investigate whether REM sleep alterations promote the development of negative memory bias in major depressive disorder.

Keywords: Major Depressive Disorder (MDD), depression, Rapid Eye Movement (REM) sleep, REM density, emotional memory consolidation

1. Introduction

Relative to individuals reporting minimal depressive symptoms, those exhibiting symptoms of depression such as despair and hopelessness have repeatedly been shown to have a greater ability to recall and recognise negative emotional information (Everaert, Duyck, & Koster, 2014; Fattahi Asl, Ghanizadeh, Mollazade, & Aflakseir, 2015; Howe & Malone, 2011). In accordance with popular cognitive models (Beck, 1967; Everaert, Koster, & Derakshan, 2012), an increasing body of research suggests that this negative memory bias may play an important role in increasing an individual's vulnerability to Major Depressive Disorder (MDD; Gotlib and Joormann, 2010).

In recent years, evidence has accumulated for the notion that Rapid Eye Movement (REM) sleep plays an important role in emotional memory consolidation (Bennion, Payne, & Kensinger, 2015; Genzel, Spoormaker, Konrad, & Dresler, 2015; Walker & van der Helm, 2009). Indeed, healthy students selectively deprived of REM sleep have been found to exhibit impaired next-day recognition performance for negative, but not neutral, images encoded pre-sleep when compared to students deprived of Non-REM (NREM) Slow-Wave Sleep (SWS; Wiesner et al., 2015). Furthermore, it has been reported that 3 h of late night REM-dominant sleep facilitates the consolidation of negative images (Groch et al., 2015) and stories (Wagner, Gais, & Born, 2001), relative to the same amount of sleep obtained in the first half of the night where REM sleep is less abundant. The active and selective role of REM sleep in negative memory consolidation is highlighted by correlational analyses, which demonstrate that greater negative memory consolidation is predicted by longer duration of REM sleep during retention intervals (Nishida, Pearsall, Buckner, & Walker, 2009; Payne, Chambers, & Kensinger, 2012). A recent

study suggests that the microstructural properties of REM sleep may also influence emotional memory consolidation, demonstrating that greater REM density - i.e. the number of Rapid Eye Movements (REMs) per minute of REM sleep - predicts greater selective consolidation of emotionally negative stories (Gilson et al., 2015).

Polysomnographic sleep research reveals that up to 70 % of MDD patients exhibit a distinct constellation of neurobiological sleep changes, the most reliable of which include a marked increase in REM sleep duration and density (Palagini, Baglioni, Ciapparelli, Gemignani, & Riemann, 2013; Pillai, Kalmbach, & Ciesla, 2011). Elevated REM density has also been observed in both healthy first-degree relatives of MDD patients (High-Risk Probands; HRPs) and remitted patients (Modell, Ising, Holsboer, & Lauer, 2002; Pillai et al., 2011), and may increase vulnerability to MDD development and relapse, respectively (Giles, Roffwarg, & Rush, 1990; Mendlewicz, 2009). Accordingly, increased REM density may be an endophenotype of MDD (Pillai et al., 2011). Given that REM sleep appears to play a selective role in negative emotional memory consolidation (Gilson et al., 2015; Groch et al., 2015; Nishida et al., 2009; Wiesner et al., 2015), it has been suggested that changes in REM sleep may increase vulnerability to the onset and recurrence of MDD by promoting the development of negative memory bias (Harrington, Pennington, & Durrant, 2017; Walker & van der Helm, 2009).

Although there is abundant research demonstrating a role for REM sleep in the consolidation of emotionally negative stimuli (Gilson et al., 2015; Groch et al., 2015; Nishida et al., 2009; Wiesner et al., 2015), the possibility that REM sleep may also influence the consolidation of positive emotional material remains largely unexplored. To our knowledge, only one polysomnography study has considered the relationship between REM sleep and the consolidation of positive memories

(Cairney, Durrant, Power, & Lewis, 2015). This study reported that greater REM sleep proportion predicts reduced positive memory consolidation, suggesting that REM sleep may inhibit the stabilization of positive material (Cairney et al., 2015). Nonetheless, the lack of research in this area obscures the question of exactly what type of memories REM sleep 'selects' to be consolidated.

The current study aimed to investigate the effect of post-learning REM sleep and SWS on recognition performance for positive, neutral and negative images in samples of participants reporting mild-to-moderate depressive symptoms and minimal depressive symptoms. These two groups of participants are referred to below as the higher Beck Depression Inventory (BDI-II; Beck, Steer, & Brown, 1996) score group and the low BDI-II score group, respectively. There is a striking absence of research exploring sleep-dependent emotional memory consolidation in healthy participants exhibiting mild-to-moderate depressive symptoms. Accordingly, the influence of depressive symptoms on emotional memory processing during REM sleep remains uncharacterised. We predicted that greater REM sleep duration would be associated with increased consolidation of negative emotional images, and that this effect would be more abundant in the higher BDI-II score group than the low BDI-II score group. Conversely, we hypothesised that SWS duration would show no relationship with the consolidation of negative emotional images. Given the lack of research on sleep-dependent consolidation of positive memories, we refrained from making any predictions regarding the relationship between sleep and the consolidation of positive images.

2. Materials and Methods

2.1. Participants

Recruitment was based on BDI-II scores obtained from a prescreen of 77 student volunteers who signed up using an online research participation system. Twenty-eight participants were selected and assigned to one of two groups based on their prescreen BDI-II scores: a low BDI-II score group or a higher BDI-II score group (see Section 2.2 for details). Participants were required to have no history of sleep, neurological, endocrine or psychiatric disorders, as assessed through self-report. Participants were also free of long-term medication (except for the female contraceptive pill) and were native English speakers.

Of the selected participants, five were excluded from final analyses for failing to obtain adequate sleep (< 90 min; n = 3) or failing to meet the eligibility criteria at one of the subsequent test sessions (i.e. they were originally assigned to the higher BDI-II score group, but their BDI-II score dropped below the cut-off boundary for this group at one of the subsequent test sessions; n = 2). Data is reported from the remaining 23 participants: 11 in the higher BDI-II score group (five male, six female) aged 19 - 24 years (21.27 ± 0.43; Mean ± SEM), and 12 in the low BDI-II score group (seven male, five female) aged 18 - 29 years (22.08 ± 0.87). For more information on participants see Table 1.

Table 1. Summary of participants' demographic data.

	Low BDI-II Score Group	Higher BDI-II Score Group	P-value
Number	12	11	-
Gender (m/f)	(7/5)	(5/6)	-
Age (years)	22.08 (0.87)	21.27 (0.43)	.428
BDI-II	3.25 (0.58)	18.64 (1.50)	< .001
STAI-T	30.50 (1.68)	47.64 (3.89)	< .001
PSQI	3.83 (0.44)	5.36 (0.62)	.055

Mean values are presented with SEM in parenthesis. Higher scores equate to higher levels of depressive symptoms, trait anxiety, or sleep quality impairment. Abbreviations: BDI-II, Beck Depression Inventory; STAI-T, Trait Anxiety Inventory; PSQI, Pittsburgh Sleep Quality Index.

Participants were asked to abstain from alcohol, caffeine, and other drugs for 24 h prior to test sessions. Participants were paid £40 for their participation. Each participant gave informed consent for this study, which was approved by the School of Psychology Research Ethics Committee at the University of Lincoln.

2.2. Participant Groups

The BDI-II measures depressive symptom severity with 21 items rated on a scale from zero to three. This self-report measure has good reliability and validity in both healthy and depressed samples (Beck et al., 1996) and is widely used in cognitive research (Everaert et al., 2014; Hindash & Amir, 2011; Newby, Lang, Werner-Seidler, Holmes, & Moulds, 2014). Prescreen data showed that BDI-II scores ranged from zero to 40, with 46 individuals reporting minimal (BDI-II cut off range: 0 - 13), 16 mild (BDI-II cut off range: 14 - 19), 12 moderate (BDI-II cut off range: 20 - 28), and three severe symptom levels (BDI-II cut off range: 29 - 63). The described BDI-II score cut-off ranges are in accordance with those suggested in the BDI-II manual (Beck et al., 1996), and are commonly used in cognitive research to group

participants according to depressive symptom severity (Everaert et al., 2014; Everaert, Tierens, Uzieblo, & Koster, 2013). In order to clearly differentiate the two groups, we selected individuals who reported the lowest BDI-II scores at the prescreen for the low BDI-II score group (BDI-II score: mean = 3.25, range = 0 - 6). All Individuals who reported BDI-II scores within the cut-off range for mild or moderate depression at the prescreen were invited to take part in this study. The individuals who accepted our invitation and successfully completed the study make up the higher BDI-II score group (BDI-II score: mean = 18.64, range = 14 - 27). As mentioned in Section 2.1, two participants who were originally assigned to the higher BDI-II score group reported BDI-II scores less than 14 during one of the subsequent test sessions and were excluded from final analyses due to this fluctuation. The BDI-II scores of the remaining participants did not fluctuate between test sessions to the extent that they no longer fit the ranges outlined above.

2.3. Stimuli

Six-hundred images were selected from the International Affective Picture System (IAPS; Lang, Greenwald, Bradley, & Hamm, 1993). IAPS images range from everyday scenes to images of injury, violence and contaminated foods, and each are rated on nine-point scales for emotional valence (1 = negative; 5 = neutral; 9 = positive) and arousal (1 = calm; 9 = exciting). Images were selected based on their valence and arousal ratings and placed into one of three emotion categories: “positive”, “neutral” or “negative”, each of which contained 200 images. Pairwise comparisons demonstrated that there was a significant difference in the mean IAPS valence rating (i.e. the valence ratings from the IAPS database) between all emotion categories (positive: [7.31 ± 0.04; Mean ± SEM]; neutral: [5.02 ± 0.02]; negative: [2.66 ± 0.05]; all pairwise $p < .001$). There was a significant difference in the mean

IAPS arousal rating (i.e. the arousal ratings from the IAPS database) for the neutral category relative to the positive and negative categories (positive: [5.18 ± 0.07]; neutral: [3.37 ± 0.06]; negative: [5.18 ± 0.06]; both $p < .001$), however, we ensured that there was no significant difference in the mean arousal rating between the positive and negative categories [$p = .990$].

Selected images were divided into two equal sets of 300 (100 positive; 100 neutral; 100 negative), which were matched as closely as possible for IAPS valence and arousal ratings, to allow separate tests for early and late sleep conditions. From each set of 300 images, 180 images were used as targets in the learning phase and the remaining 120 images were used as foils in the recognition tests. Each subset of images (i.e. targets or foils) was further divided into another two sets to allow two separate recognition tests (immediate and delayed). During each recognition test, one-half of the target images were presented, intermixed with one-half of the foil images. Three separate pseudorandom orders (with no more than three consecutive images from the same valence category) were created from each of the two subsets of learning phase images to check for order effects on memory. Learning phase and recognition test subsets and learning phase image orders were counterbalanced across participant groups and sleep conditions (see Section 2.4 for details regarding sleep conditions).

2.4. Experimental Protocol

The experimental protocol is summarised in Fig 1. All participants took part in two experimental conditions (early sleep and late sleep), separated by an interval of 14 (± 3) days. Participants arrived at the laboratory at 8.30 PM for the early sleep condition and 9.45 PM for the late sleep condition. If it was the participants' first test

session then they were asked to complete the Pittsburgh Sleep Quality Index (PSQI; a self-report measure of subjective sleep quality over the last month; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) and the Trait Anxiety Inventory (STAI-T; a self-report measure of anxiety as a personal characteristic; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Participants were then given the opportunity to prepare for bed, before electrodes were attached for polysomnographic monitoring (see Section 2.6.2 for details).

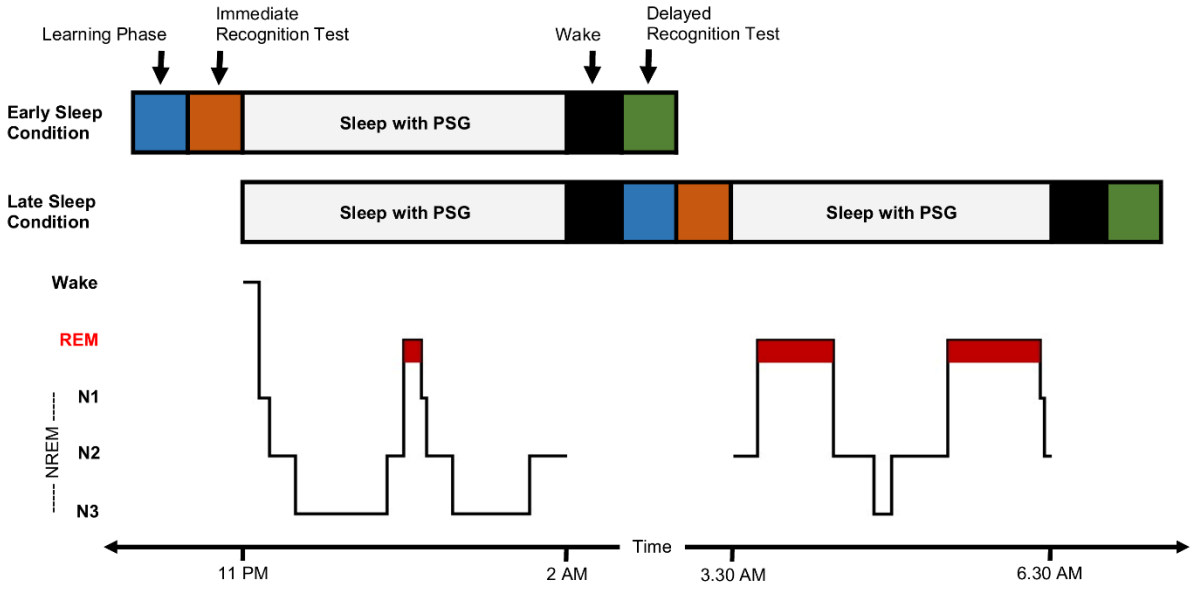

Fig 1. Pictorial representation of experimental protocol. In the early sleep condition participants began a learning phase at 10 PM which was followed by an immediate recognition test. They then slept for 3 h between 11 PM and 2 AM, before being given 30 min to recover from sleep inertia in preparation for a delayed recognition test. We expected this early sleep interval to be rich in SWS. In the late sleep condition participants slept for 3 h between 11 PM and 2 AM, before being given 30 min to recover from sleep inertia in preparation for the learning phase and immediate recognition test at 2.30 AM. They then slept again for another 3 h between 3.30 AM and 6.30 AM, before being given 30 min to recover from sleep inertia in preparation for a delayed recognition test. We expected this late sleep interval to be rich in REM sleep. Abbreviations: PSG, Polysomnography; SWS, Slow-Wave Sleep; REM, Rapid Eye Movement sleep; N1 - N3, stages of Non-REM (NREM) sleep.

In the early sleep condition, electrode attachment was followed by a learning phase and an immediate recognition test (see Section 2.5 for details) which started at 10 PM and lasted approximately 50 min. This was followed by 3 h of sleep between 11 PM and 2 AM, which was expected to be rich in SWS. Participants were then given 30 min to recover from sleep inertia before completing a delayed recognition test which lasted approximately 30 min. In the late sleep condition, electrode attachment was immediately followed by 3 h of sleep between 11 PM and 2 AM, which preceded a 30 min recovery interval, learning phase, and immediate recognition test. Participants were then given a further 3 h sleep opportunity between 3.30 AM and 6.30 AM which was expected to be rich in REM sleep. Another 30 min recovery interval was provided before participants completed the delayed recognition test. Sleep condition order was counterbalanced across participant groups.

2.5. Learning Phases and Recognition Tests

Prior to each learning phase and delayed recognition test participants indicated their level of sleepiness on a scale from one (alert, wide awake) to seven (fighting sleep) using the Stanford Sleepiness Scale (SSS; Hoddes, Dement, & Zarcone, 1972). During the learning phase participants were presented with 180 target images (60 positive, 60 neutral, 60 negative). This was immediately followed by an immediate recognition test where participants were presented with 90 target images (30 positive, 30 neutral, 30 negative) intermixed with 60 foil images (20 positive, 20 neutral, 20 negative). The delayed recognition test was identical to the immediate recognition test, except that it contained the other half of the images. Image sets were counterbalanced across recognition test sessions (i.e. each half set of images was presented an equal number of times in immediate recognition tests and delayed recognition tests).

The learning phases and recognition tests are summarised in Fig 2. At the beginning of the learning phase participants saw a black screen with a white central fixation cross for 500 ms. They were then presented with the first image (size: 15 cm x 11 cm) for 750 ms which appeared in the centre of the screen. Participants were then prompted to provide a valence rating for the image on a scale from one (very negative) to nine (very positive) using corresponding keys. Once a valence rating had been submitted, participants were prompted to rate the image for emotional arousal on a scale from one (low arousal) to nine (high arousal). Once an arousal rating had been submitted, participants were again presented with the fixation cross followed by the second image. This pattern continued until every image had been viewed and rated. Participants were instructed to provide their emotion ratings quickly and spontaneously, and were informed prior to learning phases that their memory for the images would be tested immediately after learning, and again once they had slept.

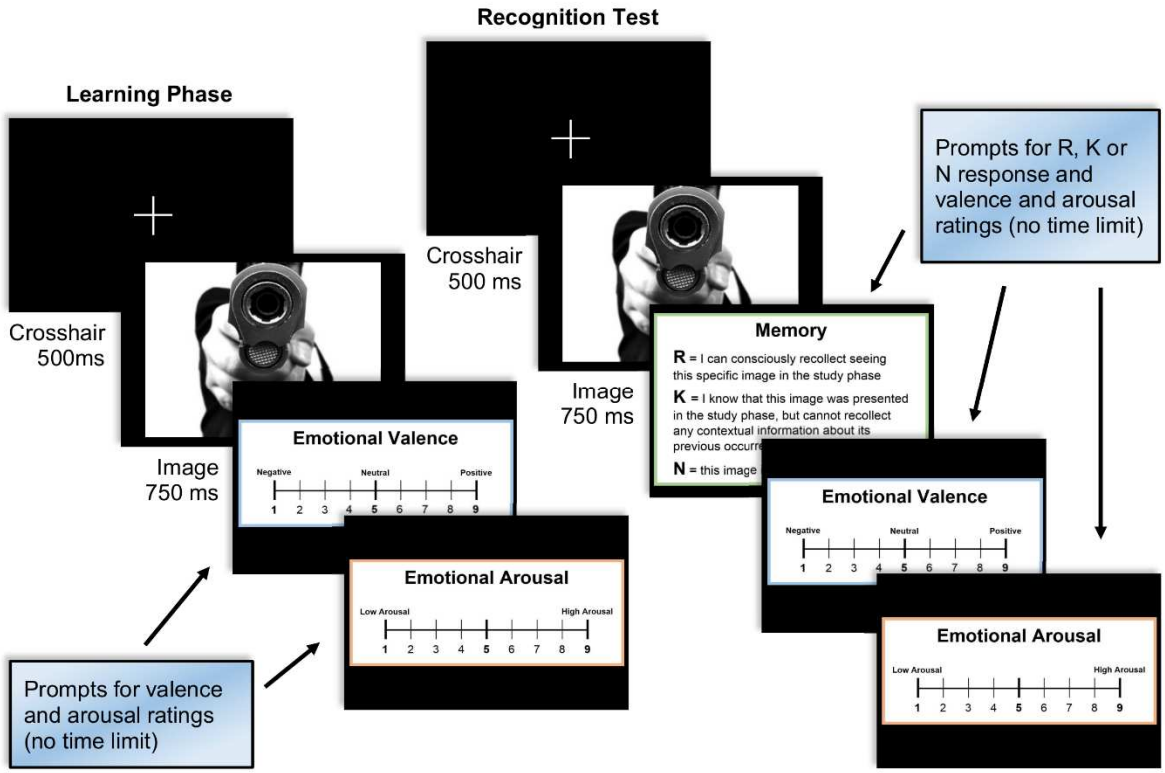

Fig 2. Learning phase and recognition test. During learning phases and recognition tests participants were required to rate each image on a scale from one to nine in terms of emotional valence (1 = very negative, 9 = very positive) and emotional arousal (1 = low arousal, 9 = high arousal). During recognition tests participants were additionally required to provide a memory rating to indicate whether they could recollect seeing the image before (R response), they thought the image was familiar (K response), or they thought the image was new (N response).

The recognition tests were identical to the learning phases except that before providing their emotion ratings participants were required to make a remember/ know/ new judgement for the image using corresponding keys (i.e. R, K or N). A remember (R) judgment indicated that the participant could consciously recollect seeing that specific image during the prior learning phase. A know (K) judgment indicated the participant knew the image was familiar, but could not consciously recollect details about its previous occurrence. A new (N) judgement indicated that the participant believed they had not seen the image during the prior learning phase. A “remember” response indicates recollection of the episodic details of an item,

whereas a “know” response reflects item familiarity in the absence of recollection (Mickley & Kensinger, 2008); these different forms of remembering are thought to be supported by different neural processes (Dobbins, Kroll, & Yonelinas, 2004; Yonelinas, 2002). For this study, we were particularly interested in examining remember responses (for more information see Section 2.7.1). Participants were asked to provide their memory judgements as quickly and accurately as possible. There was no time constraint for memory judgments or emotion ratings in any learning phase or recognition test.

2.6. Equipment

2.6.1. Experimental Task

Stimulus presentation and data collection used custom-written scripts running in MATLAB© R2015a using the Psychophysics Toolbox Version 3 extension (Kleiner et al., 2007) on a Toshiba Satellite laptop with a 15.6 ” screen. Participant responses were recorded using the laptop keyboard.

2.6.2. Polysomnography

Overnight sleep monitoring was carried out at the University of Lincoln Sleep and Cognition Laboratory using an Embla© N7000 polysomnography system. Silver-silver chloride (Ag–AgCl) electrodes were attached using EC2© electrode cream after the scalp was cleaned with NuPrep© exfoliating agent. Scalp electrodes were attached at six standard locations according to the international 10 - 20 system (Homan, Herman, & Purdy, 1987): C3, C4, F3, F4, O1, and O2 - each referenced to the contralateral mastoid (A1 and A2). Left and right electrooculogram, left, right and upper electromyogram, and a ground electrode were also attached. In addition, the Patient Unit was attached to record physiological signals including movement and

respiration. All electrodes were verified to have a connection impedance of < 5 000 Ω. All signals were digitally sampled at a rate of 200 Hz.

2.7. Data Analysis

2.7.1. Behavioural Data Analysis

Although our experimental task provided an index of both recollection (R responses) and familiarity (K responses) recognition performance (see Fig 2), we were particularly interested in recollection as this has previously shown emotion-specific sensitivity to sleep (Cairney et al., 2015; Sterpenich et al., 2007). Therefore, we made this the primary focus of our investigation. Data from recollection trials were first converted to *d'* scores (*d'* = Z (hits / hits + misses) – Z (false alarms / false alarms + correct rejections); extreme proportions of zero or one were replaced with values of "1 / (2N)" and "1 – 1 / (2N)", respectively, where N equals the number of trials upon which the proportion is based; Macmillan & Kaplan, 1985), a signal detection process widely used in memory studies to account for response bias (Macmillan & Creelman, 2005). This was done separately for positive, neutral and negative image trials for each participant. In accordance with previous research (Cairney et al., 2015; Groch et al., 2015; Nishida et al., 2009), to measure the time course of memory consolidation we created a difference measure, which we refer to as 'behavioural consolidation', by subtracting *d'* scores at immediate recognition testing from *d'* scores at delayed recognition testing. The resulting behavioural consolidation scores provide indices of the emotional memory processes taking place across the 3 h sleep interval.

Our main analysis used to investigate the roles of REM sleep and SWS in the consolidation of positive, neutral and negative images in the two participant groups

was a two (participant group: low BDI-II score group; higher BDI-II score group) x two (sleep condition: early sleep; late sleep) x three (image valence: positive; neutral; negative) mixed-measures ANOVA with behavioural consolidation as the dependent variable. This was followed up with two-way ANOVAs and t-tests where appropriate. Our primary hypothesis was that there would be a significant three-way 'group x 'sleep condition' x 'image valence' interaction, and that this would be driven by greater consolidation of negative images in the late sleep condition by the higher BDI-II score group, relative to the low BDI-II score group.

2.7.2. Sleep Data Analysis

Each participant's sleep data was divided into 30 s epochs and independently scored by two trained sleep researchers (level of agreement: 84.96 % ± 7.63 %), according to standardised criteria (Rechtschaffen & Kales, 1968), using REM Logic © 1.1. This gave the duration and proportion of NREM sleep stages one (N1) and two (N2), SWS, and REM, as well as measures of sleep efficiency and total sleep time. Additionally, REMs occurring during REM sleep phases were scored to calculate REM density and the total number of REMs. Each eye movement which was detectable above the background noise, exhibited a rapid time course, and appeared simultaneously on both right and left electrooculogram channels was counted, regardless of the amplitude of the eye movement (Aserinsky, 1973; Hong, Gillin, Dow, Wu, & Buchsbaum, 1995; Khalsa, Conroy, & Duffy, 2002).

The role of particular sleep stages in memory consolidation was investigated using planned parametric correlation tests between the duration of N2, SWS, and REM, all of which have been implicated in sleep-dependent consolidation (Born & Wilhelm, 2012; Fogel, Smith, & Cote, 2007; Smith, 2001), and behavioural

consolidation, separately for positive, neutral and negative images. We also examined the correlation between behavioural consolidation and both REM density and total number of REMs, as these REM sleep parameters have also been shown to influence memory consolidation (Gilson et al., 2015; Smith, Nixon, & Nader, 2004).

3. Results

3.1. Participant Demographics

The participants' demographic characteristics are shown in Table 1. To compare demographic characteristics between the two participant groups we conducted independent-samples t-tests, which confirmed that the higher BDI-II score group had significantly higher BDI-II scores [$t(21) = 9.91$, $p < .001$], and STAI-T scores [$t(21) = 4.17$, $p < .001$], than the low BDI-II score group. The higher BDI-II score group also had marginally greater PSQI scores [$t(21) = 2.03$, $p = .055$]. There was no significant difference between the two participant groups regarding age [$t(21) = 0.81$, $p = .428$].

3.2. Alertness

To compare alertness between the two sleep conditions we conducted paired-samples t-tests on SSS ratings, which demonstrated that participants rated themselves as sleepier during the learning phase in the late sleep condition (3.52 ± 0.26), relative to the early sleep condition (2.35 ± 0.16) [$t(22) = 5.05$, $p < .001$]. Furthermore, participants rated themselves as marginally sleepier during the delayed recognition test in the early sleep condition (3.26 ± 0.24), relative to the late sleep condition (2.78 ± 0.19) [$t(22) = 1.97$, $p = .061$].

To compare alertness between the two participant groups we conducted independent-samples t-tests on SSS ratings, which demonstrated that during the learning phase in the late sleep condition, the higher BDI-II score group rated themselves as marginally sleepier (4.00 ± 0.40) than the low BDI-II score group (3.08 ± 0.29) [$t(21) = 1.87$, $p = .075$]. Self-reported sleepiness did not differ significantly between the two participant groups during any other learning phase or recognition test in either sleep condition [all $p \geq .251$].

3.3. Sleep Parameters

Sleep parameter data are shown in Table 2. To compare sleep parameters between the two sleep conditions, we conducted paired-samples t-tests on duration of each sleep stage, total sleep time, sleep efficiency, number of REMs during REM sleep, and REM density (number of REMs / REM sleep duration), separately for each participant group. The analyses demonstrated that relative to the early sleep condition, REM sleep duration was greater in the late sleep condition in both the higher BDI-II score group [$t(10) = 8.55$, $p < .001$] and the low BDI-II score group [$t(11) = 5.26$, $p < .001$]. Conversely, relative to the late sleep condition, SWS duration was greater in the early sleep condition in both the higher BDI-II score group [$t(10) = 7.35$, $p < .001$] and the low BDI-II score group [$t(11) = 6.88$, $p < .001$]. Moreover, in the higher BDI-II score group, total sleep time was marginally greater in the late sleep condition relative to the early sleep condition [$t(10) = 2.01$, $p = .073$]. There were no other significant differences between the two sleep conditions for either participant group regarding duration of N1, N2, total sleep time, or sleep efficiency [all $p \geq .308$].

Table 2. Sleep parameters data separately for each group and sleep condition.

	Low BDI-II Score Group			Higher BDI-II Score Group		
	Early sleep	Late sleep	P-value	Early sleep	Late sleep	P-value
N1 (min)	7.50 (1.26)	6.50 (1.12)	.568	6.32 (1.52)	6.68 (1.59)	.869
N2 (min)	75.87 (3.10)	72.54 (7.44)	.636	79.00 (3.65)	84.99 (5.87)	.474
SWS (min)	61.46 (6.65)	26.13 (3.64)	< .001	55.71 (3.93)	28.41 (2.54)	< .001
REM (min)	15.17 (2.69)	48.20 (5.26)	< .001	8.77 (1.79)	49.81 (3.78)	< .001
TST (min)	159.99 (3.84)	153.37 (9.49)	.528	149.25 (6.23)	169.89 (5.65)	.073
Efficiency (%)	97.53 (1.21)	92.64 (4.62)	.308	94.55 (2.24)	96.52 (2.22)	.568
Total Nr of REMs	58.08 (10.60)	256.92 (36.91)	< .001	41.27 (12.97)	380.82 (51.13)	< .001
REM density	3.42 (0.66)	5.34 (0.48)	.041	3.56 (0.85)	7.93 (1.03)	.004

Mean values are presented with SEM in parenthesis. Abbreviations: REM, Rapid Eye Movement sleep; N1 and N2, stages of non-REM sleep; SWS, Slow-Wave Sleep; TST, Total Sleep Time; Nr, number; REMs, Rapid Eye Movements; BDI-II, Beck Depression Inventory.

As expected, the total number of REMs was greater in the late sleep condition relative to the early sleep condition in both the higher BDI-II score group [$t(10) = 6.02$, $p < .001$], and the low BDI-II score group [$t(11) = 5.23$, $p < .001$]. In addition, it is known that REM density increases over the time course of the sleep episode in successive REM sleep periods (Aserinsky, 1973; Benoit, Parot, & Garma, 1974; Benson & Zarcone, 1993; Khalsa et al., 2002), consequently, REM density was also found to be greater in the late sleep condition, relative to the early sleep condition, in both the higher BDI-II score group [$t(10) = 3.67$, $p = .004$], and the low BDI-II score group [$t(11) = 2.31$, $p = .041$].

Using independent-samples t-tests, we then compared sleep parameters between the two participant groups, separately for each sleep condition. It was found that the low BDI-II score group obtained marginally more REM sleep in the early sleep condition, relative to the high BDI-II score group [$t(21) = 1.94$, $p = .066$]. However, there were no other significant differences between the two participant groups in either sleep condition regarding duration of N1, N2, SWS, or REM sleep, total sleep time, or sleep efficiency [all $p \geq .150$].

Relative to the low BDI-II score group, the higher BDI-II score group had significantly greater REM density in the late sleep condition [$t(21) = 2.35$, $p = .029$], but not the early sleep condition [$t(21) = 0.13$, $p = .895$]. Total number of REMs were also marginally greater in the higher BDI-II score group, relative to the low BDI-II score group, in the late sleep condition [$t(21) = 1.99$, $p = .060$], but not the early sleep condition [$t(21) = 1.01$, $p = .324$].

3.4. Subjective Ratings of Valence and Arousal

Subjective valence and arousal ratings from the learning phase and recognition tests are shown in Supplementary Table 1. To ensure that subjective ratings of valence and arousal were in accordance with those used to categorise images as positive, neutral or negative (Lang et al., 1993), we compared subjective valence and arousal ratings obtained during the learning phase between image categories, separately for each sleep condition, using paired-samples t-tests. It was revealed that the mean valence ratings, collapsed across participant groups, were significantly different for each emotion category in both the early [all $p < .001$] and late [all $p < .001$] sleep conditions, with positive images rated as the most positive and negative images rated as the most negative.

Participant ratings also revealed that during the learning phase, in both sleep conditions, negative images elicited a significantly greater degree of arousal than both neutral images [early sleep condition: $t(22) = 7.44$, $p < .001$; late sleep condition: $t(22) = 7.85$, $p < .001$] and positive images [early sleep condition: $t(22) = 2.52$, $p = .019$; late sleep condition: $t(22) = 2.91$, $p = .008$]. Furthermore, positive images were rated as higher in emotional arousal than neutral images [early sleep condition: $t(22) = 5.43$, $p < .001$; late sleep condition: $t(22) = 6.21$, $p < .001$]. These results suggest that ratings of emotional valence provided by participants during the learning phase in this study were in line with those from the IAPS database. However, the finding that participants in this study rated negative images as higher in arousal than positive images is contrary to the arousal ratings from the IAPS database (see Section 2.3). This finding is in accordance with other studies which used images from the IAPS database (e.g. Cairney et al., 2015), and may be due to methodological differences in the way that emotional responses were collected.

To compare emotionality ratings between the two participant groups we conducted independent-samples t-tests on valence and arousal ratings obtained during the learning phase, separately for each sleep condition. It was revealed that, in the early sleep condition, the low BDI-II score group rated positive images as significantly more positive than the higher BDI-II score group [$t(21) = 2.16$, $p = .043$]. There were no other significant differences between the two participant groups in valence or arousal ratings for positive, neutral or negative images during the learning phase in either sleep condition [valence: all $p \geq 342$; arousal: all $p \geq .266$].

3.5. Recognition Performance

As described in Section 2.7.1, the results presented here are focused exclusively on recognition and behavioural consolidation scores for recollection responses. Behavioural consolidation is calculated as the difference between *d'* scores at pre- and post- sleep recognition tests [*d'* delayed recognition – *d'* immediate recognition].

3.5.1. Immediate Recognition Performance

Immediate recognition performance data are available in Table 3. To test for any effects of sleep condition, participant group, or image valence on immediate recognition performance we performed a two x two x three mixed-measures ANOVA, with factors "group" (low BDI-II score group/ higher BDI-II score group), "sleep condition" (early/ late) and "image valence" (positive/ neutral/ negative), on immediate recognition scores. The analysis revealed a significant main effect of image valence [$F(2, 42) = 3.66$, $p = .034$, $\eta_p^2 = 0.148$], however there were no other significant main effects or interactions [all $p \geq .111$], confirming similar initial learning between the two participant groups and in the two sleep conditions. Paired-samples t-tests on immediate recognition scores (*d'*), collapsed across sleep conditions and participant groups, revealed that recognition performance for neutral images was significantly greater than both positive images [$t(22) = 2.16$, $p = .042$] and negative images [$t(22) = 2.41$, $p = .025$]. There was no difference in immediate recognition scores between positive and negative images [$t(22) = 0.57$, $p = .574$].

Table 3. Immediate recognition performance (*d'*) data for recollection (R) responses separately for each group, image valence, and sleep condition.

	Low BDI-II Score Group		**Higher BDI-II Score Group**	
	Early sleep	Late sleep	Early sleep	Late sleep
Positive images	3.26 (0.23)	2.99 (0.22)	3.54 (0.22)	3.38 (0.22)
Neutral images	3.74 (0.29)	3.27 (0.26)	3.49 (0.34)	3.75 (0.35)
Negative images	3.18 (0.21)	3.09 (0.28)	3.51 (0.19)	3.10 (0.28)

Mean values are presented with SEM in parenthesis. Abbreviations: BDI-II, Beck Depression Inventory.

3.5.2. Behavioural Consolidation

Behavioural consolidation data are available in Fig 3 and Supplementary Table 2. To initially investigate the possible relationship between participant group, sleep condition and image valence, we performed a two x two x three mixed-measures ANOVA, with factors "group" (low BDI-II score group/ higher BDI-II score group), "sleep condition" (early/ late) and "image valence" (positive/ neutral/ negative), on behavioural consolidation scores. We found a significant three-way interaction between sleep condition, image valence, and group [$F (2, 42) = 3.28$, $p = .047$, $\eta_p^2 = 0.135$]. There was also a significant two-way interaction between image valence and group [$F (2, 42) = 3.99$, $p = .026$, $\eta_p^2 = 0.160$]. Overall behavioural consolidation (i.e. regardless of image valence) was not affected by group [$F (1,21) = 1.93$, $p = .179$, $\eta_p^2 = 0.084$] or sleep condition [$F (1,21) = 1.52$, $p = .231$, $\eta_p^2 = 0.068$]. Behavioural consolidation was also unaffected by image valence [$F (2,42) = 1.64$, $p = .206$, $\eta_p^2 = 0.072$].

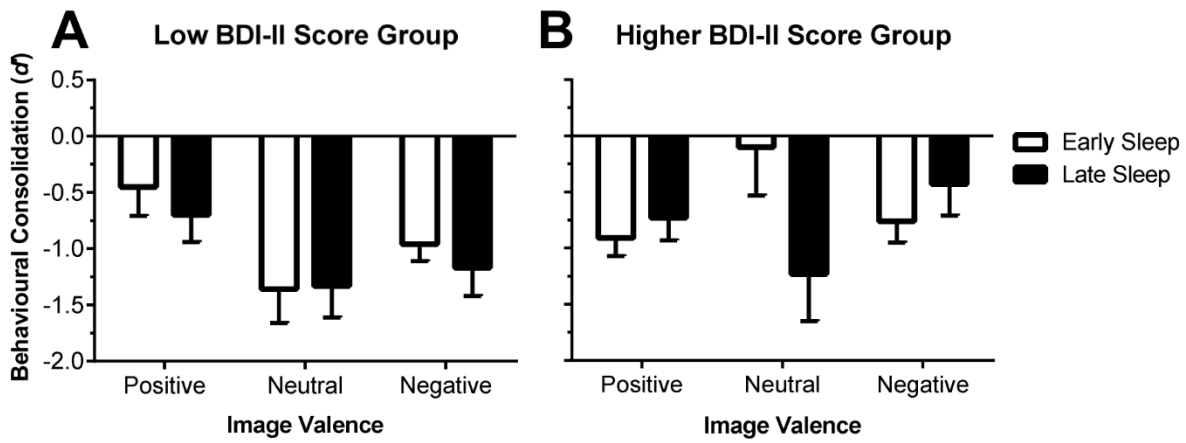

Fig 3. Mean behavioural consolidation [*d'* delayed recognition – *d'* immediate recognition] for recollection (R) responses separately for each group, sleep condition, and image valence. Panel A, low BDI-II score group data; panel B, higher BDI-II score group data. Error bars represent SEM. Abbreviations: BDI-II, Beck Depression Inventory.

To explore the significant participant group x sleep condition x image valence interaction, we performed two x three mixed-measures ANOVAs with factors "sleep condition" (early/ late) and "image valence" (positive/ neutral/ negative) on behavioural consolidation scores, separately for each participant group (low BDI-II score group/ higher BDI-II score group). We found a significant interaction between sleep condition and image valence in the higher BDI-II score group [$F(2, 20) = 4.73$, $p = .021$, $\eta_p^2 = 0.321$], but not in the low BDI-II score group [$F(2, 22) = 0.17$, $p = .845$, $\eta_p^2 = 0.015$], suggesting that REM sleep and SWS had differential effects on memory consolidation according to image valence in the higher BDI-II score group.

As demonstrated in Fig 3, the significant sleep condition x image valence interaction in the higher BDI-II score group appears to be driven, at least partially, by greater consolidation of neutral images in the early sleep condition. To test our hypothesis that late sleep would be associated with greater behavioural consolidation of negative images in the higher BDI-II score group relative to the low BDI-II score group, we conducted independent-samples t-tests comparing

behavioural consolidation between the two participant groups, separately for each sleep condition and emotion category. As suggested by Fig 3, behavioural consolidation of neutral images in the early sleep condition was indeed greater in the higher BDI-II score group (-0.10 ± 0.43), relative to the low BDI-II score group (-1.36 ± 0.30; Fig 4a) [t (21) = 2.44, p = .023]. However, offering some support to our hypothesis, we also found marginally greater behavioural consolidation of negative images in the late sleep condition in the higher BDI-II score group (-0.43 ± 0.28), relative to the low BDI-II score group (-1.17 ± 0.25; Fig 4b) [t (21) = 1.96, p = .064]. No other significant differences were revealed [all p ≥ .156].

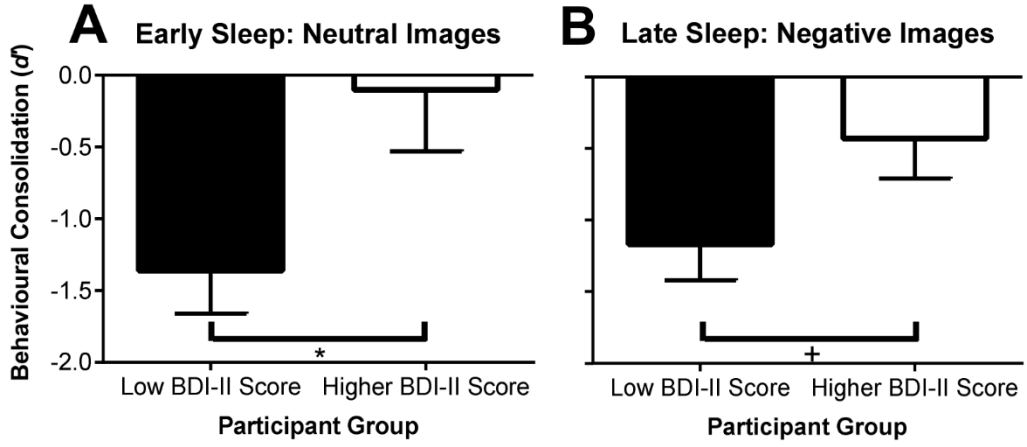

Fig 4. Mean behavioural consolidation [*d'* delayed recognition – *d'* immediate recognition] for recollection (R) responses. Panel A, behavioural consolidation of neutral images in the early sleep condition was significantly greater in the higher BDI-II score group; panel B, behavioural consolidation of negative images in the late sleep condition was marginally greater in the higher BDI-II score group. Error bars represent SEM. *, p = .023; +, p = .064. Abbreviations: BDI-II, Beck Depression Inventory.

3.6. Sleep Stage Correlations

To investigate the relationship between specific sleep parameters and emotional memory consolidation, the correlation between behavioural consolidation scores and the duration of sleep stages N2, SWS, and REM, and both REM density

and total number of REMs, was investigated, separately for each emotion valence, sleep condition, and participant group. In the early sleep condition, a greater duration of N2 was associated with decreased consolidation of neutral images for participants in the higher BDI-II score group [r = .756, p = .007]. No other significant correlations were revealed [all p ≥ .138].

The sample sizes for the correlational analyses were very small when examining participant groups separately. To test for effects with sufficient power, we also ran exploratory correlational analyses collapsed across participant groups. It was revealed that, in the late sleep condition, a greater number of REMs was associated with significantly greater behavioural consolidation of negative images [r = .486, p = .019] (Fig 5a). Interestingly, it was also found that in the late sleep condition greater REM density was associated with a marginal increase in behavioural consolidation of negative images [r = .395, p = .062] (Fig 5b). Furthermore, in the early sleep condition greater duration of N2 was associated with marginally decreased consolidation of neutral images [r = .-.356, p = .095]. No other significant correlations were revealed [all p ≥ .120].

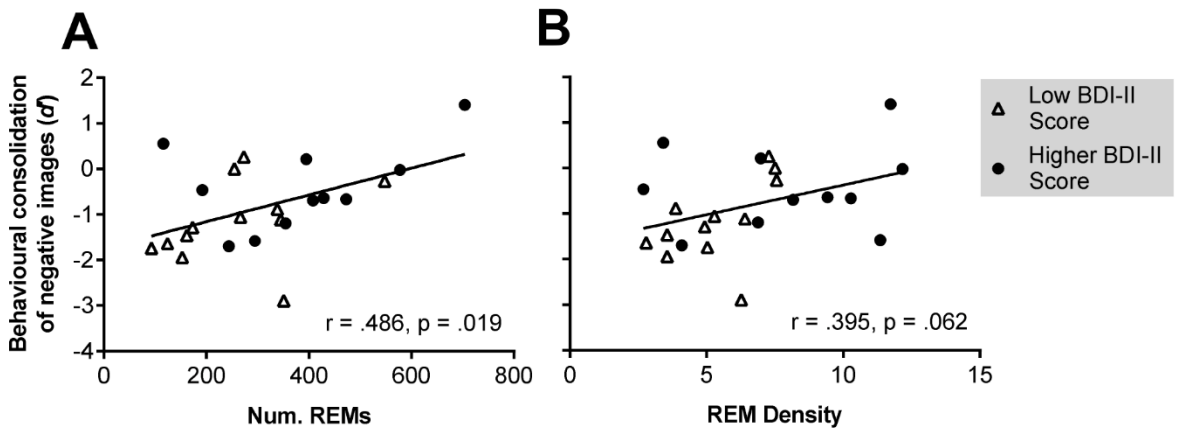

Fig 5. REM sleep parameters and behavioural consolidation [*d'* delayed recognition – *d'* immediate recognition] of negative images for recollection (R) responses in the late sleep condition. Panel A, greater number of REMs during REM sleep was associated with greater behavioural consolidation of negative images; panel B, greater REM density was marginally associated with greater behavioural consolidation of negative images. Abbreviations: BDI-II, Beck Depression Inventory; REM, Rapid Eye Movement; REMs, Rapid Eye Movements; Num., Number.

Given that the higher BDI-II score group exhibited significantly greater REM density and marginally greater number of REMs in the late sleep condition than the low BDI-II score group (see Section 3.3), we sought to investigate whether the positive correlations between the measures of REM sleep microstructure (i.e. number of REMs and REM density) and behavioural consolidation of negative images may be modulated by BDI-II score. Correlational analyses revealed that there was indeed a significant positive correlation between BDI-II score and REM density [r = .477, p = .021], but not number of REMs [r = .343, p = .109], in the late sleep condition.

To examine the contributions of BDI-II score and REM sleep parameters to the consolidation of negative images, we ran two regression analyses with negative behavioural consolidation in the late sleep condition as the dependent variable, firstly with BDI-II score and number of REMs, and secondly with BDI-II score and REM density, as the predictor variables. It was revealed that number of REMs and BDI-II score significantly predicted behavioural consolidation of negative images [F (2, 20)

= 4.462, p = .025, R^2 = .309]. Number of REMs contributed marginally to the prediction [p = .064], however, there was no contribution of BDI-II score [p = .163]. The second regression analysis showed that REM density and BDI-II score marginally predicted behavioural consolidation of negative images [F (2, 20) = 2.90, p = .078, R^2 = .225], however, neither of the variables added significantly to the prediction [BDI-II score: p = .196; REM density: p = .274].

4. Discussion

We investigated the roles of REM sleep and SWS in the consolidation of emotionally positive, neutral and negative images in samples of healthy individuals reporting either minimal depressive symptoms or mild-to-moderate depressive symptoms. This study set out principally to explore whether REM sleep is involved in the selective consolidation of negative memories, especially in participants reporting higher levels of depressive symptoms. Our data showed differential effects of REM sleep and SWS on memory consolidation according to valence in the higher BDI-II score group, but not in the low BDI-II score group. Comparing the two participant groups revealed that SWS supported the consolidation of neutral images more readily in the higher BDI-II score than the low BDI-II score group. The higher BDI-II score group also consolidated marginally more negative images during the REM sleep- rich condition, offering some support to our hypothesis. In addition, our data showed that the microstructural properties of REM sleep (i.e. number of REMs and REM density) influenced negative memory consolidation during the late sleep retention interval.

Over the years, evidence has accumulated which demonstrates that REM sleep and SWS serve distinct functions in memory consolidation. Notably, REM sleep has frequently been shown to support the consolidation of emotionally salient memories (Gilson et al., 2015; Groch et al., 2015; Nishida et al., 2009; Payne et al., 2012; Wiesner et al., 2015), whereas SWS benefits consolidation in non-emotional memory tasks (Stickgold, 2005). However, to our knowledge, our results are the first to demonstrate differential effects of REM sleep and SWS on emotional and neutral memory consolidation in individuals reporting symptoms of depression. Although these findings are preliminary, and future studies including larger sample sizes are required before definitive conclusions can be made, our results may have implications for the way in which we understand the relationship between sleep and emotional memory in depression vulnerability.

The most robust difference in memory consolidation between our two participant groups was greater consolidation of neutral images during SWS in the higher BDI-II score group. This finding was surprising, as we expected any between-group differences to stem from measures of negative emotional memory consolidation. There is abundant evidence to suggest that SWS is critically involved in the consolidation of hippocampus-based, emotionally neutral declarative memories (Stickgold, 2005). However, our finding that this effect is more prominent in participants exhibiting depressive symptoms has gathered less empirical support. Nonetheless, a recent study by Nishida and colleagues (2016) found that greater SWS duration predicted greater overnight motor memory consolidation in participants with MDD, but not control participants (Nishida, Nakashima, & Nishikawa, 2016). These findings may suggest that SWS plays a more crucial role in

the consolidation of emotionally neutral memories in individuals exhibiting depressive symptoms, relative to minimally depressed individuals.

It is also notable that the low BDI-II score group retained more positive memories than the higher BDI-II score group in the early sleep condition (Fig 3), which may indicate that, for the higher BDI-II score group, SWS favoured the consolidation of neutral memories in a “trade-off” between positive and neutral memories. However, the between-group differences in positive behavioural consolidation in the early sleep condition are modest [p = .156], and does not provide an adequate explanation for the observed differences in neutral memory consolidation. Interestingly, it has recently been shown that slow-wave activity over the prefrontal cortex during the first NREM sleep episode is greater in depressed adolescents than matched controls (Tesler et al., 2016). The authors of this study speculate that the increase of frontal slow-wave activity in MDD may reflect an altered pruning of synapses in this area, which results in a failure to reduce irrelevant connections. Our findings may provide support for this notion; however, this is a tentative explanation, and future work is required to clarify the mechanisms underlying the observed increase in SWS dependent neutral memory consolidation in individuals reporting mild-to-moderate depressive symptoms.

We hypothesised that REM sleep would support the consolidation of negative emotional images, particularly in the higher BDI-II score group. It is believed that REM sleep supports the consolidation of emotionally salient memories through the reactivation of, and coherence between, neural regions implicated in emotional memory processing during wake, in particular the amygdala, entorhinal cortex and medial prefrontal cortex (Hutchinson & Rathore, 2015; Maquet et al., 1996; Nir & Tononi, 2010). According to the Sleep to Forget and Sleep to Remember (SFSR)

hypothesis, emotional memory biases in MDD may be supported by an increase in REM sleep duration, which commonly occurs during depressive episodes (Pillai et al., 2011), and disproportionately amplifies the strength of emotionally salient memories (Walker & van der Helm, 2009).

Offering some support to our hypothesis, our results showed that the higher BDI-II score group consolidated marginally more negative memories during late sleep than the low BDI-II score group. However, there were no between-group differences in REM sleep duration in this sleep condition, suggesting that greater negative memory consolidation in the higher BDI-II score group was due to factors other than greater REM sleep duration. Intriguingly, in the late sleep condition the higher BDI-II score group exhibited significantly greater REM density, and a marginally greater number of REMs, than the low BDI-II score group. It could be argued that these differences in REM sleep microstructure may underlie the marginal differences in negative emotional memory consolidation between the two participant groups. Indeed, a positive correlation between negative memory consolidation and both REM density and number of REMs was found when data was collapsed across participant groups. However, as observed in previous research (Luik, Zuurbier, Whitmore, Hofman, & Tiemeier, 2015), these microstructural properties of REM sleep correlated with depressive symptom severity, obscuring their influence on emotional memory consolidation. Although number of REMs was found to marginally predict negative memory consolidation after adjusting for BDI-II score, further research is required before we can conclude that REMs are closely related to emotional memory consolidation processes.

Indeed, evidence supporting a direct relationship between REMs and emotional memory consolidation in humans is sparse. However, a recent study

found that greater REM density during a morning nap predicted greater memory performance for sad stories, but not neutral stories (Gilson et al., 2015). Several neuroimaging studies have shown that the amygdala, hippocampal gyrus, and entorhinal cortex show transient activations in conjunction with REM sleep REMs (Abe, Ogawa, Nittono, & Hori, 2004; Andrillon, Nir, Cirelli, Tononi, & Fried, 2015; Ioannides et al., 2004). These findings may suggest that greater frequency of REMs predicts greater activity in neural regions thought to support emotional memory consolidation during REM sleep.

An additional factor which could explain the marginally increased late-night negative memory consolidation exhibited by the higher BDI-II score group in this study relates to mechanisms which support the *encoding* of emotional material. According to the Affect Tagging and Consolidation (ATaC) model, heightened amygdala activity during the encoding of negative memories interacts with REM sleep alterations to promote the development of negative memory bias in individuals vulnerable to MDD (Harrington et al., 2017). It is well reported that MDD patients exhibit greater amygdala reactivity to negative emotional stimuli than healthy controls (Costafreda et al., 2013; Perlman et al., 2012; Stuhrmann et al., 2013; Suslow et al., 2010), and amygdala reactivity to negative words has been shown to correlate positively with BDI-II scores in healthy participants (BDI-II score range = 0 – 10; Laeger et al., 2012). As such, although our results revealed no between-group differences in immediate recognition performance, it is plausible that the negative images used in this study may have elicited greater amygdala responses in the higher BDI-II score group, leading to the increased consolidation of these images during subsequent REM sleep in this group. Additional neuroimaging is required to test this hypothesis.

It is widely believed that the alterations in REM sleep microstructure which characterise MDD represent a vulnerability marker for the disorder, rather than a mere epiphenomenon (Modell & Lauer, 2007; Palagini et al., 2013; Pillai et al., 2011). Indeed, increased REM density has been shown to increase the likelihood of developing MDD in HRPs (Modell et al., 2002; Modell & Lauer, 2007; Steiger & Kimura, 2010). This study has shown that a greater number of REMs significantly predicts greater consolidation of negative memories. However, given that this relationship was only found when both participant groups were analysed together, and was only marginal after controlling for BDI-II score, the mechanisms underlying microstructural REM sleep alterations in depression vulnerability remain elusive. Future research should examine the relationship between REMs and emotional memory consolidation in a large sample of participants with similar depressive symptomatology. This approach will help to disentangle the contribution of REMs from depressive symptoms to the consolidation of negative emotional memories.

Another important line of research which should be pursued in the future relates to the possible relationship between biased encoding mechanisms and REM sleep in the development of emotional memory bias in depression. As discussed, the marginally greater consolidation of negative memories during late sleep in the higher BDI-II score group in this study may be related to increased amygdala activity during the encoding of negative images in this group (Bennion et al., 2015; Costafreda et al., 2013; Dannlowski et al., 2010; Harrington et al., 2017). Future research in this area will benefit from the inclusion of fMRI scanning during encoding phases to determine whether amygdala activity during encoding interacts with REM sleep in the development of negative memory bias. The genetic basis of both amygdala hyperactivity and increased REM density should also be investigated, as the

identification of specific genetic variants involved in these two vulnerability factors is likely to improve the way in which we understand the development and underlying pathophysiology of depression. Finally, mechanisms underlying sleep deprivation therapy (Benedetti & Colombo, 2011; Maturana et al., 2015) and antidepressant medications which suppress REM sleep (Mayers & Baldwin, 2005; Palagini et al., 2013; Steiger & Kimura, 2010) should be investigated. It seems likely that their efficacy may relate to the prevention of emotional memory processing which typically occurs during REM sleep.

4.1. Limitations

Between-group comparisons of the participants' demographic characteristics showed that the higher BDI-II score group reported greater trait anxiety than the low BDI-II score group. It is commonly reported that symptoms of depressive and anxiety disorders often co-occur (de Jong, Sportel, de Hullu, & Nauta, 2012; Sartorius, Üstün, Lecrubier, & Wittchen, 1996; Tiller, 2012), and are influenced by overlapping genetic factors (Eley & Stevenson, 1999; Taporoski et al., 2015). Indeed, similarly to depressive disorders, anxiety disorders have also been shown to be related to emotional memory bias (Coles & Heimberg, 2002; Eysenck & Byrne, 1994; Memarian & Azaraein, 2015). Of note, a recent study found that cueing of words during sleep benefited the extraction of emotional gist information from negative stimuli in socially anxious youths, but not healthy controls (Groch et al., 2017), suggesting that sleep may also influence emotional memory bias in anxiety disorders. Consequently, it is unclear whether the emotion-specific effects of REM sleep on memory consolidation in the high BDI-II score group are due to greater symptoms of depression, or greater trait anxiety.

Similarly, the higher BDI-II score group also reported marginally poorer sleep quality in the month preceding the study than the low BDI-II score group. This is unsurprising, considering that sleep disturbances are reported by up to 90 % of MDD patients (Baglioni et al., 2011; Palagini et al., 2013), however, these between-group differences in sleep quality may have also influenced emotional memory processing (Tempesta, De Gennaro, Natale, & Ferrara, 2015).

A further limitation relates to the differences in subjective alertness between sleep conditions in this study. Our split-night design successfully delivered greater REM sleep duration in the late sleep condition, and greater SWS duration in the early sleep condition, without significantly influencing the duration of N1 or N2. However, participants reported feeling sleepier during the learning phase in the late sleep condition relative to the early sleep condition, and marginally sleepier during the delayed recognition test in the early sleep condition relative to the late sleep condition. Future research may benefit from implementing a 1 h recovery interval to allow adequate recovery from sleep inertia.

4.2. Conclusion

Our study has shown that REM sleep and SWS differentially affect emotional and neutral memory consolidation in individuals reporting mild-to-moderate depressive symptoms. Furthermore, SWS has been shown to support the consolidation of neutral memories more readily in individuals reporting depressive symptoms than those reporting minimal depressive symptoms. Offering some support to our hypothesis, individuals reporting depressive symptoms also consolidated marginally more negative memories during the REM sleep- rich retention interval than individuals reporting minimal depressive symptoms. Finally,

our data suggests that the microstructural properties of REM sleep such as quantity of REMs may influence the consolidation of negative emotional memories. Further research is required to elucidate the relationship between REM sleep and emotional memory consolidation in the pathology of MDD.

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